COMPUTER SCIENCE
TECHNICAL REPORT SERIES

UNIVERSITY OF MARYLAND
COLLEGE PARK, MARYLAND
20742

(1)

(14) TR-610

(15) DAAG53-76C-0138,

ARPA Order-3206

(11) Nov[redacted]77

(12) 13p.

(6) THINNING ALGORITHMS FOR GRAYSCALE PICTURES.

(10) Charles R./Dyer
Azriel/Rosenfeld

Computer Science Center
University of Maryland
College Park, MD 20742

(9) Technical rept.,

ABSTRACT

Elongated black objects in black-and-white pictures can be "thinned" to arcs and curves, without changing their connectedness, by (repeatedly) deleting black border points whose deletion does not locally disconnect the black points in their neighborhoods. This technique generalizes to gray-scale pictures if we use a weighted definition of connectedness: two points are "connected" if there is a path joining them on which no point is lighter than either of them. We can then "thin" dark objects by changing each point's gray level to the minimum of its neighbors' gray levels, provided this does not disconnect any pair of points in its neighborhood. Examples illustrating the performance of this technique are given.

The support of the U. S. Army Night Vision Laboratory under Contract DAAG53-76C-0138 (ARPA Order 3206) is gratefully acknowledged, as is the help of Mrs. Shelly Rowe

403 018

1. Introduction

Elongated black objects in black-and-white pictures can be "thinned" to arcs and curves, without changing their connectedness, by repeatedly deleting black border points whose deletion does not locally disconnect the black points in their neighborhoods. In order to prevent objects two points wide from vanishing completely, this deletion process should be performed from one side at a time -- e.g., first delete north border points that satisfy the conditions, then south, then east, then west, and so on repeatedly. [In any case, the deletion should not be performed from two opposite sides at once, though it may be performed simultaneously from two adjacent sides (e.g., north and east, then south and west, and so on repeatedly), if a somewhat more complicated algorithm is used.] In order to prevent thin arcs from shrinking at their ends, or isolated points from vanishing, black points that have fewer than two black neighbors should not be deleted. A number of such thinning algorithms have been described in the literature; see [1] for a review, and [2] for a mathematical treatment of the simple algorithm described above*.

---

*There are two versions of these algorithms, depending on whether or not we regard diagonally adjacent points as neighbors. In this note we regard only horizontal and vertical points as neighbors, but it is straightforward to define a version of our technique that allows diagonal neighbors as well. We assume here that dark points have higher values than light points.

In [3] a generalization of the notion of connectedness to grayscale pictures was proposed. In this "fuzzy" definition of connectedness, two points are called "connected" if there is a path joining them that contains no point lighter than both of them. Using this definition, we can formulate a grayscale thinning algorithm in which a point is set equal to the lightest of its neighbors (including itself) if doing so does not disconnect any pair of its neighbors. The details of this algorithm are presented in Section 2, and some examples are given and discussed in Section 3.

2. The grayscale thinning algorithm

It is not trivial to define an exact analog of the black-and-white thinning algorithm in the grayscale case. In particular, it is not immediately clear how to generalize the condition that a black point must have at least two black neighbors. Moreover, the requirement that no pair of neighbors be disconnected may be very strong, since it rules out changing the center point (to 1) in cases like

```
50  50  0
50  50  2
50  1   0
```

since this disconnects the 2 from the 50's.

The approach that we have adopted here is to define the neighbor count and disconnection conditions in terms of a threshold that is proportional to the gray level range in the neighborhood. Specifically, given the neighborhood

```
abc
def
ghi
```

let us define the gray level range in this neighborhood as

$$R = \max(b,d,e,f,h) - \min(b,d,e,f,h) + 1$$

and let R' be some fixed fraction of this range ($0 \leq R' \leq R$). We can then formulate the conditions for changing the center point e of the neighborhood as follows:

(1) At least two of b,d,f,h have values $\geq e-R'$

[This corresponds to the requirement that a black point e must have at least two black neighbors.]

2) For each pair of b,d,f,h, let m be the pair's minimum; then either $e<m-R'$, or there is a path joining the pair within the neighborhood, but not involving e (e.g., for the pair b,f, the path must contain either c or a,d,g,h,i) such that for every point p on the path we have $p \geq m-R'$.

[This corresponds to the requirement that deletion of e not disconnect any pair of its black neighbors. In our case, "deletion" means setting e equal to the minimum of itself and its neighbors. If $e<m-R'<m$, then the pair of neighbors whose minimum is m has no effect on e, since e is smaller than their minimum. Otherwise, we must insure that these neighbors are still connected; we do this by requiring that there be a path joining them whose lightest point $\geq m-R'$. Note that this allows us to change the center point to 1 in the example

```
50   50   0
50   50   2
50    1   0
```

provided that R' is at least 4% of R, since in this case we have $R = 50$, $R' \geq 2$, and there is still a path from 2 to the 50's whose points satisfy $p \geq 2-2 = 0$.]

In order to apply this algorithm from one or two sides at a time (north, etc.), we could define e to be a north border point if $b<e-R'$, and so on. A simpler approach is to simply replace e by the minimum of itself and its north neighbor b, without regard to their relative values; if $b<e-R'$, this will change e significantly, but otherwise it will not. [By the same reasoning, we need never check whether e is a "border point" at all; if it is an "interior point", we can replace it by the minimum of its neighbors' values without changing it significantly.] We have chosen to apply the algorithm from two sides at a time; at alternate steps we replace e by the minimum of b,e,f or by the minimum of d,e,h, provided conditions (1-2) are satisfied. All points that satisfy these conditions are replaced simultaneously; the algorithm is "parallel". R' was taken to be 10% of R in our experiments, but the results are not sensitive to this choice.

3. Examples and discussion

Figure 1 shows the results of applying seven iterations of this algorithm to a picture of some chromosomes. (Each iteration consists of the two steps described in Section 2, involving the minimum of b,e,f and of d,e,h, respectively.) We see that each chromosome is reduced to a thin, 4-connected "skeleton". Figure 2 shows three iterations applied to pictures of characters and terrain. Figure 3 shows an application of the algorithm to the output of an edge detector (based on differences of averages); the thick, fuzzy streaks of edge values are reduced to thin curves.

In these examples, connectedness appears to be preserved, but this is not absolutely guaranteed, since we have applied the algorithm from two sides at once rather than from one side at a time (see [2]). In fact our algorithm allows the connectedness between dark points to be weakened, e.g., in the case

$$\begin{matrix} 0 & 12 & 0 \\ 0 & 10 & 0 \\ 0 & 12 & 0 \end{matrix}$$

we can change the center 10 to 0. A more sophisticated version of the algorithm would define the degree of connectedness of two points as the gray level of the lightest point on the darkest path joining them, and would change a point only if doing so did not weaken the connectedness of any pair of its neighbors. In any event, the algorithm seems to be useful in a variety of cases, since it provides a thinning procedure that does not require prior thresholding, thus making it possible to avoid premature commitment to a threshold.

References

1. R. Stefanelli and A. Rosenfeld, Some parallel thinning algorithms for digital pictures, J.ACM 18, 1971, 255-264.

2. A. Rosenfeld, A characterization of parallel thinning algorithms, Info. Control 29, 1975, 286-291.

3. A. Rosenfeld, Fuzzy digital topology, Computer Science Technical Report 573, University of Maryland, College Park, MD, Sept. 1977.

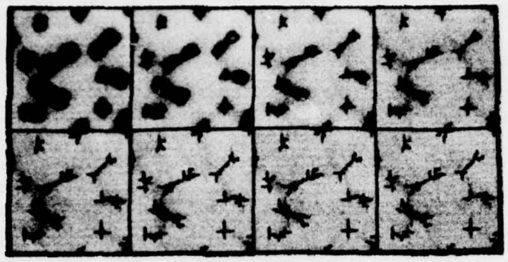

Figure 1.

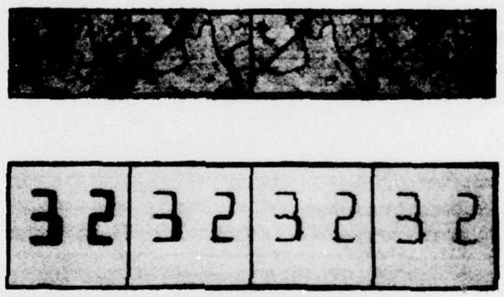

Figure 2.

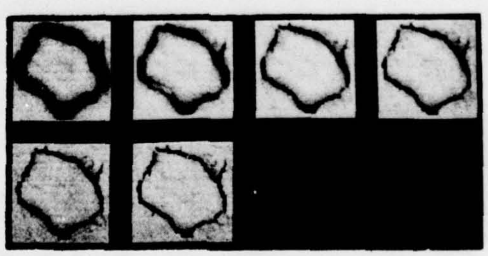

Figure 3.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) THINNING ALGORITHMS FOR GRAYSCALE PICTURES		5. TYPE OF REPORT & PERIOD COVERED Technical
		6. PERFORMING ORG. REPORT NUMBER TR-610
7. AUTHOR(s) Charles R. Dyer and Azriel Rosenfeld		8. CONTRACT OR GRANT NUMBER(s) DAAG53-76C-0138
9. PERFORMING ORGANIZATION NAME AND ADDRESS Computer Science Ctr. Univ. of Maryland College Pk., MD 20742		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Night Vision Lab. Ft. Belvoir, VA 22060		12. REPORT DATE November 1977
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Image processing
Pattern recognition
Connectedness
Thinning

20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Elongated black objects in black-and-white pictures can be "thinned" to arcs and curves, without changing their connectedness, by (repeatedly) deleting black border points whose deletion does not locally disconnect the black points in their neighborhoods. This technique generalizes to grayscale pictures if we use a weighted definition of connectedness: two points are "connected" if there is a path joining them on which no point is lighter than either of them.* ~~We can~~ then "thin" dark

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

*It is then possible to

ABSTRACT (cont'd)

objects by changing each point's gray level to the minimum of its neighbors' gray levels, provided this does not disconnect any pair of points in its neighborhood. Examples illustrating the performance of this technique are given.